Lesson Plan for Calorimeters

A High School Physical Science Lesson Featuring Engineering Design

Lesson Summary:

Grade Level: High School **Preparation Time:** 1 hour

Cost: $100-$125 initial cost **Activity Time:** 100 – 180 minutes
$85-$100 recurrent cost

Key Vocabulary: **Clean-up Time:** 15 minutes
adiabatic, calorimeter, calorimetry, constant, enthalpy, equilibrate, heat, heat of solution

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Item to Purchase	Notes
100mL Beakers*	Ordered at Nurnberg Scientific: 125-0005
Food Grade KCl (Potassium Chloride Salt)	Lab grade is ideal but much more costly (~$30 for the same amount)
Bottled Distilled Water	Bottled water OK too
Wood Craft Sticks	The craft sticks will serve as the body of the chassis Online www.flowerfactory.com large quantities www.discountschoolsupply.com
Alochol-based Thermometer*	Ordered at Nurnberg Scientific: 485-0009 Long, with no backing
Styrofoam Cups	Must hold around 250mL water
Solo Cups	Must hold around 250mL water Stiffness is what's important
Cloth (Varying Types)	Cut into 6"x6" squares
Felt	Cut into 6"x6" squares
Masking Tape	Scotch tape works too
Paper (Varying Types)	0.00
Scissors	0.00
Aluminium Foil	0.00
Bubble Wrap	Ordered at Walmart: 000359711
Rubber Bands	Bought at Office Depot: 856657
Safety Goggles*	Ordered at Walmart: 550905940
Nitrile Gloves	Ordered at Nurnberg Scientific: 285-0300 Large size fits most
100mL Graduated Cylinder*	Ordered at Nurnberg Scientific: 125-0101 Glass alternative ($3.83): 125-0005
Dust Mask	Ordered at Nurnberg Scientific: 440-0047

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1—Lesson Overview

1.1—Introduction

In this high school–level engineering design lesson[1], students learns the basics of heat transfer by constructing a constant-pressure calorimeter and using it to measure the heat of solution of potassium chloride in water.

- ✔ **Part 1** is reading activity where students learn a little about calorimeters including useful mathematical equations.
- ✔ **Part 2** is an exploration activity, called "Wait, What Just Happened?" in which the teacher demonstrates a chemical reaction, and students reflect on it in a worksheet.
- ✔ **Part 3** is an engineering design activity in which students work in groups to design and build their own calorimeters. They calculate and compare the measured heat absorbed to the predicted heat of solution. They also evaluate and recommend improvements to their calorimeters.

1.2—Lesson Breakdown with Engineering Design

Engineering Design Steps	Activity	Handout	Product
1. Define a problem that addresses a need	**Part 1:** Reading **Part 3A:** Engineering	Reading Handout Engineering Design Handout	Problem statement
2. Identify criteria, constraints, and priorities	**Part 3A:** Engineering	Engineering Design Handout	Description of criteria, constraints, and priorities
3. Describe relevant scientific principles and knowledge.	**Part 1** Reading	Reading Handout	Vocab Alert Worksheet
4. Investigate possible solutions and use the concept of trade-offs to compare solutions in terms of criteria and constraints.	**Part 3A:** Engineering	Engineering Design Handout	Solution Proposal
5. Design and construct at least one proposed solution.	**Part 3A:** Engineering	Engineering Design Handout	Solution Proposal
	Part 3B: Evaluation and Improvement	Evaluation and Improvement Handout	Solution Redesign
6. Test a proposed solution(s), collect and process relevant data and incorporate modifications based on data from testing or other analysis.	**Part 3A:** Engineering	Engineering Design Handout	Solution Test Data Calculations
	Part 3B: Evaluation and Improvement	Evaluation and Improvement Handout	Solution Analysis Solution Redesign
7. Analyze data, identify uncertainties, and display data so that the implications for the solution being tested are clear	**Part 3A**: Engineering	Engineering Design Handout	Solution Test Data Calculations
	Part 3B: Evaluation and Improvement	Evaluation and Improvement Handout	Solution Analysis Solution Redesign
8. Recommend a proposed solution, identify its strengths and weaknesses, and describe how it is better than alternative designs as well as identifying further	**Part 3A**: Engineering	Design Handout	Solution Proposal
	Part 3B: Evaluation and Improvement	Evaluation and Improvement Handout	Solution Analysis Solution Redesign

[1] Developed by Rachel Aazerah and based on a lesson from TeachEngineering called Counting Calories. See bit.ly/19Qf3RC

engineering that might be done to refine the recommendation.			

1.3—Pre-Requisite Knowledge

1.3.1—Algebra

Students need to know how to perform basic algebraic manipulation of equations and substitution techniques.

1.3.2—Chemistry

Students should be aware that chemicals interact in reactions that change the chemical and/or physical properties of a system. Also, students should have some experience with mole balances or stoichiometry (quantitative aspect of chemistry).

1.3.3—Physical Science

Students should be familiar with concept of energy, that it can be exchanged, and that it comes in different forms.

1.4—Motivation for this Lesson

This lesson develops an understanding of heat transfer and heats of solution. It also helps students understand how we measure these heat transfer and the problems we encounter in trying to do this accurately and inexpensively in real-world situations.

2—Teacher Background Information

2.1—Glossary of Terms

Calorimeter: A device designed to measure transferred energy, or heat.

Calorimetry: The applied use of a calorimeter.

Heat Capacity: The amount of energy required to raise or lower a given amount of a substance by one unit temperature at a constant pressure.

Endothermic: A reaction that consumes heat energy**.**

Enthalpy: A special value used in engineering to describe the amount of energy in a system including pressure and volume, relative to a reference state.

Exothermic: A reaction that produces heat energy.

Heat: Energy transferred between two systems as a result of a temperature difference.

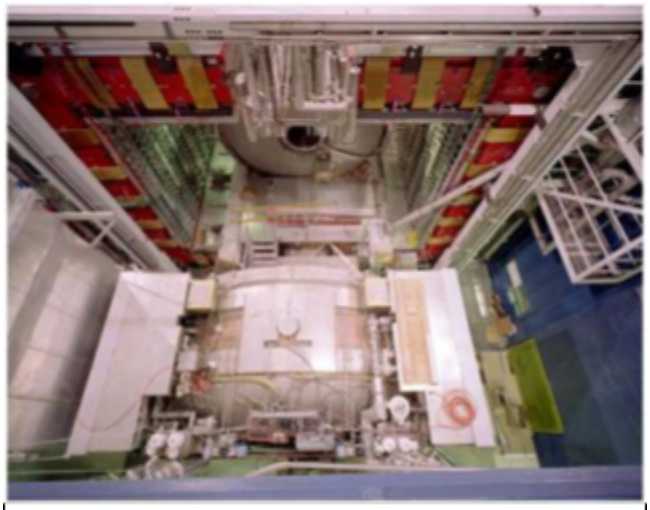

Figure 1: The DZero Liquid Argon Calorimeter is used to detect subatomic particles in complex quantum mechanical experiments.
Source: http://bit.ly/19Qf3RC

Heat of Solution: The energy generated or consumed when dissolving one substance in another.

2.2— Scientific Concepts and Disciplinary Core Ideas

Chemical engineers design and operate among other things large plants and processes that make usable products from chemicals, ranging from electrical power, food products, medicines, materials, fuels and refined chemicals. In order to safely and efficiently apply and control these processes, an engineer must know how much heat will be generated in a given reaction. If too much heat is generated, proteins denature, products burn or decompose, or a reactor might violently explode. If too little heat is generated, chemicals do not react, not enough energy is generated, or the wrong products are favored. Additionally, an engineer has to be aware of how the process equipment itself will affect the chemical process. By being able to predict how much heat will be produced in a reaction (as well as pressure), systems can be designed with specific tolerances in mind and reaction conditions maximized. See **Figure 1** for an example of a calorimeter used in real life.

Note: For a complete list of scientific concepts and disciplinary core ideas covered in this lesson, see **Appendix 1**.

2.3—Lesson Materials

Note: For a complete and up-to-date listing of materials in a printable shopping list format, see **Appendix 2: Complete Materials Listing**.

3—Preparation

3.1—Preparation Part 1: Reading

3.1.1—Printed Materials

- □ *Reading Handout*—one per student
- □ *Vocab Alert Handout*—one per student

3.1.2—Activity Materials

- □ *None*

3.1.3—Preparation Steps

1. Make one copy of the *Article Handout* and the accompanying *Vocab Alert Handout* for each student.

3.2—Preparation Part 2: Exploration

3.2.1 Wait, What Just Happened?

3.2.1—Printed Materials

- □ *Exploration Handout* – one per student
- □ *Wait What Just Happened Handout* – one per student.
- □ *Wait What Just Happened Answers Resource* – one per teacher.

3.2.1—Activity Materials

- □ 2 100mL beakers
- □ Water
- □ Thermometer
- □ Potassium chloride
- □ Craft sticks

3.2.3—Preparation Steps:

1. Cool two beakers of 100mL of water to just-about freezing.
2. Gather materials, supplies and worksheets.

3.3—Preparation Part 3: Engineering Design

Note: Plan to have students in **groups of 2** for the Engineering Design activity.

3.3.1—Printed Materials: Engineering Design Activity

- □ *Engineering Design Activity Handout* – one per student
- □ *Evaluation and Improvement Handout* – one per student
- □ *Evaluation and Improvement Answers Resource* – one per teacher.

3.3.2—Activity Materials: Engineering Design Activity

For each group of 2-3 students:

- □ 2-3 Styrofoam® coffee cups
- □ 2-3 paper cups
- □ KCl (potassium chloride), 25 mg*
- □ cloth
- □ felt
- □ foam
- □ thermometer
- □ water
- □ rubber bands
- □ 100 ml beaker
- □ tape
- □ paper
- □ any other materials that may be beneficial for a team's design (cardboard, egg cartons, cheese cloth, cotton balls, etc..)

To share with the entire class:

- □ scissors
- □ graduated cylinder if you want to give students the option of increasing the precision of their measurement of water over using a graduated beaker
- □ balance-beam scale or other means of weighing the potassium chloride
- □ aluminum (Al) foil roll as source of 6 inch x 6 inch squares

3.3.3—Preparation Steps: Engineering Design Activity

1. Provide several different materials and cups for the students, and let them decide what would best insulate their reaction.
    a. The Styrofoam cups are good insulators (which is part why we use them for hot coffee).
    b. One of the better ways to use Styrofoam cups is to nest them in each other, creating a double layer of insulation.
    c. If possible, avoid air space above the water and below the nested cup.
    d. A cap is also important to prevent heat escaping into the air.
2. Provide cloth and plastic for use as caps, in addition to regular coffee cup caps.
3. Have students create some variations on this general theme based on their knowledge of calorimeters.

4—Activity Instructions

4.1—Activity Part 1: Reading (30 minutes)

1. Pass out the *Vocab Alert Handout* and have students rate their knowledge of the article's key vocabulary.

2. Pass out the *Reading Handout* for students to read and discuss.
3. Once students are finished with the article they should re-rate the vocabulary words as well as take notes on their meaning.

4.2—Activity Part 2: Exploration (30 to 60 minutes)

1. Handout the *Exploration Handout* and give students time to complete it.
2. Perform the calorimeter demonstration.
    a. Cool two beakers of water to just-about freezing.
    b. Place enough craft sticks, or the thin piece of wood, on a flat surface, ensuring that the beaker fits on top of the wood/sticks.
    c. Pour some of the ice-cold water from the first beaker onto the wood/popsicle-sticks.
    d. Place the second beaker on top of the wood, making sure there is water between the wood and glass.
    e. In the second beaker, drop a few teaspoons of Potassium Chloride and stir well using a stirring rod or a thermometer.
    f. Use a thermometer to measure the temperature as it drops below 0°C (or 32°F, the freezing point of water), even though no ice has formed inside the beaker.
    g. After a couple minutes of the beaker water being at a temperature below the freezing point of water, lift the beaker off the table.
    h. If the demo was successful, the wood should be frozen to the beaker.
3. Ask students how much energy it might take to do this per mole of water. (A mole of water is equal to 18 grams). Tell them they need to design a way to measure how much heat is absorbed in dissolving this Potassium Chloride.
4. After the demonstration, have the students read the *Wait What Just Happened Handout*.
5. After they have finished reading the background information, the students should answer the worksheet questions. Next, discuss places where heat can be lost, such as the air, a table or even from a calorimeter.

4.3—Activity Part 3: Engineering Design (60 to 90 minutes)

4.3.1 – Activity Part 3A: Initial Design

Note: Students should use gloves and goggles at all times when using the Potassium Chloride (KCl). Remind the students not to eat the KCl, and not to rub it in their eyes.

Note: The KCl may become lumped together in a large chunk and need to be broken up. To prevent this from happening over and over again, store it in an airtight container in a dry location.

Note: If the calorimeter loses too much heat to surroundings, the temperature might not have a large enough change to measure or observe. Try using more Potassium Chloride, ensuring that it is well mixed, and touch the calorimeter as little as possible. Contact with hands will actually add heat to the system.

1. Show the class the materials available to them for their calorimeter design.

Figure 2: A Sample Calorimeter
Source: http://bit.ly/19Qf3RC

2. As a class, discuss some of the qualities of the different materials.
    a. How is a paper cup different than a Styrofoam cup?
    b. How is foil different than felt?
3. Hand out the *Engineering Design Handout*.
4. Divide the students into **groups of 2** and have them brainstorm ideas for what they think would be the most efficient calorimeter.
5. Have each group design a calorimeter on paper, using the materials at their disposal.
6. Distribute supplies to each group.
7. As groups complete their design, have them conduct a test to ensure the calorimeter will actually hold water and is more or less insulated.
    a. For example, have the students fill their calorimeter with hot water.
    b. If they can feel the warmth on the outside, then a design iteration (redesign) should be considered.
2. Check to make sure the devices are feasible. If they are not, direct students to keep thinking and designing. See **Figure 2** for an example of what a calorimeter might look like.
    a. A feasible device should be able to hold water, and be made of something somewhat insulating.
    b. A cup should probably be used in the design.
    c. Ensure that each group includes access points for thermometer and stir device. Sign off on feasible designs.
3. Following the procedure and using the formulas provided in *Engineering Design Handout,* each group of students develops a satisfactory calorimeter. They then record measurements as they dissolve KCl in water and use their measurements to calculate the heat absorbed. They also calculate the predicted head of solution of KCl.

4.3.2 Activity Part 3B: Evaluation and Improvement

Students use the results of Part 3A to calculate experimental error, evaluate their original design, and then propose improvements. They should use the *Evaluation and Improvement Handout*.

Appendix 1A: 2009 Oregon Standards Relating to This Lesson

Engineering Design

H.4D.1 Define a problem and specify criteria for a solution within specific constraints or limits based on science principles. Generate several possible solutions to a problem and use the concept of trade-offs to compare them in terms of criteria and constraints.

H.4D.2 Create and test or otherwise analyze at least one of the more promising solutions. Collect and process relevant data. Incorporate modifications based on data from testing or other analysis.

H.4D.3 Analyze data, identify uncertainties, and display data so that the implications for the solution being tested are clear.

H.4D.4 Recommend a proposed solution, identify its strengths and weaknesses, and describe how it is better than alternative designs. Identify further engineering that might be done to refine the recommendations.

Interaction and Change

H.2P.3 Describe the interactions of energy and matter including the Law of Conservation of Energy.

Appendix 1B: 2014 Oregon Standards (NGSS) Relating to This Lesson

Alignment to Next Generation Science Standards

Performance Expectations

- **HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**
- **HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.**
- **HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**
- **HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).** [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]
- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.** [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]

Science and Engineering Practices

Asking Questions and Defining Problems

- Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.
- Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)

Constructing Explanations and Designing Solutions

- Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories.
- Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)
- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1)
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)

ETS1.B. Designing Solutions to Engineering Problems

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (secondary to HS-ESS3-2),(secondary to HS-ESS3-4)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)

Cross Cutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4)

Appendix 2: Complete Materials Listing

Materials List

For Teacher demonstration:

- □ 2- 100 mL beakers
- □ KCl (potassium chloride)*
- □ water
- □ a thin, lightweight piece of wood or 6-8 Popsicle® sticks or wooden Craft Sticks
- □ thermometer
- □ stirring device (such as a Popsicle(or wooden craft) stick or coffee stirrer)

For each group of 2-3 students:

- □ 100 ml graduated beaker
- □ 2-3 Styrofoam® coffee cups
- □ 2-3 paper cups
- □ KCl (potassium chloride), 25 mg*
- □ cloth
- □ felt
- □ foam
- □ thermometer
- □ 1 stir rod
- □ water
- □ rubber bands
- □ tape
- □ paper
- □ any other materials that may be beneficial for a team's design (cardboard, egg cartons, cheese cloth, cotton balls, etc..)

To share with the entire class:

- □ scissors
- □ graduated cylinder if you want to give students the option of making more precise measurements than a graduated beaker will allow.
- □ balance-beam scale or other means of weighing the potassium chloride
- □ aluminum (Al) foil roll as source of 6 inch x 6 inch squares

* sodium chloride (NaCl) can be substituted for potassium chloride (KCl) but the heat of solution will be lower.

Buyer's Guide

Item Information			Quantity: Class		Local Retail Ext Costs:			Online Ext Costs: Class		
Item to Purchase	Re usable	Store Type	30	40	Ea.	30	40	Ea.	30	40
100mL Beakers*	yes	Science supply co.	12	16	$3.83	$45.96	$61.28	$3.83	$45.96	$61.28
Food Grade KCl (Potassium Chloride Salt)	no	Grocery, Science supply co.	1	1	$2.99	$2.99	$2.99	$2.99	$2.99	$2.99
Bottled Distilled Water	no	Grocery	5	7	$1.00	$5.00	$7.00	$1.00	$5.00	$7.00
Wood Craft Sticks	no	Craft, Dollar, variety	11	15	$0.01	$0.15	$0.20	$0.01	$0.15	$0.20
Alochol-based Thermometer*	yes	Science supply co.	11	15	$11.00	$121.00	$165.00	$11.00	$121.00	$165.00
Styrofoam Cups	no	Grocery	31	41	$0.01	$0.31	$0.41	$0.01	$0.31	$0.41
Solo Cups	no	Grocery; some variety	31	41	$0.16	$4.96	$6.56	$0.16	$4.96	$6.56
Cloth (Varying Types)	yes	Grocery	33	43	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Felt	yes	Grocery	33	43	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Masking Tape	no	Grocery, Dollar	11	15	$1.79	$19.69	$26.85	$1.79	$19.69	$26.85
Paper (Varying Types)	no	0	151	201	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Scissors	yes	Dollar	11	15	$1.00	$11.00	$15.00	$1.00	$11.00	$15.00
Aluminium Foil	no	0	1	1	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
Bubble Wrap	no	0	31	41	$0.17	$5.27	$6.97	$0.17	$5.27	$6.97
Rubber Bands	no	Office, Grocery	1	1	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
Safety Goggles*	yes	Grocery, Home Improvement, Science supply co.	31	41	$1.99	$61.69	$81.59	$1.99	$61.69	$81.59
Nitrile Gloves	no	Science supply co.	31	41	$0.27	$8.37	$11.07	$0.27	$8.37	$11.07
100mL Graduated Cylinder*	yes	Science supply co.	1	1	$3.17	$3.17	$3.17	$3.17	$3.17	$3.17
Dust Mask	no	Science supply co.	31	41	$0.21	$6.51	$8.61	$0.21	$6.51	$8.61
				Total*	$0.00	$70.16	$91.93	$0.00	$70.16	$91.93
				Shipping	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
				Total with Shipping	$0.00	$70.16	$91.93	$0.00	$70.16	$91.93

* Items marked with a "*" are left out of the totals for the cost of Classroom Deployment under the assumption that most high school chemistry classrooms would have these items or their equivalent.

Buyer's Guide Notes

Item to Purchase	Notes
100mL Beakers*	Ordered at Nurnberg Scientific: 125-0005
Food Grade KCl (Potassium Chloride Salt)	Lab grade is ideal but much more costly (~$30 for the same amount)
Bottled Distilled Water	Bottled water OK too
Wood Craft Sticks	The craft sticks will serve as the body of the chassis Online www.flowerfactory.com large quantities www.discountschoolsupply.com
Alochol-based Thermometer*	Ordered at Nurnberg Scientific: 485-0009 Long, with no backing
Styrofoam Cups	Must hold around 250mL water
Solo Cups	Must hold around 250mL water Stiffness is what's important
Cloth (Varying Types)	Cut into 6"x6" squares
Felt	Cut into 6"x6" squares
Masking Tape	Scotch tape works too
Paper (Varying Types)	0.00
Scissors	0.00
Aluminium Foil	0.00
Bubble Wrap	Ordered at Walmart: 000359711
Rubber Bands	Bought at Office Depot: 856657
Safety Goggles*	Ordered at Walmart: 550905940
Nitrile Gloves	Ordered at Nurnberg Scientific: 285-0300 Large size fits most
100mL Graduated Cylinder*	Ordered at Nurnberg Scientific: 125-0101 Glass alternative ($3.83): 125-0005
Dust Mask	Ordered at Nurnberg Scientific: 440-0047

Appendix 3: Assessment

Pre-Activity Assessment

Brainstorming

In small groups, have the students engage in open discussion. Remind students that no idea or suggestion is "silly." All ideas should be respectfully heard. Encourage wild ideas and discourage criticism of ideas. Before showing students the available supplies, have students begin to think about how to make a calorimeter the most effectively. Should they use a glass jar vs. a plastic container vs. a paper or foam cup. Give them time to come up with wild ideas as well as feasible ideas so that they begin to think like engineers.

Wait, What Just Happened Worksheet?

Instruct the students to complete the worksheet. Review their answers to gauge their mastery of the subject.

Activity-Embedded Assessment

Engineering Design Handout. Have the students complete the worksheet**.** Review their answers to gauge their mastery of the key concepts.

Post-Activity Assessment

Evaluation and Enhancement Worksheet

Have the students complete the worksheet. Review their answers to gauge their mastery of the key concepts.

Appendix 4: Resources and Extensions

To add another real-world dimension to the activity, give each group a starting amount of fake money (for example, Thermodollars or Mole dollars) and require them to "buy" each item. This puts some constraints on their designs, such as only being able to afford two cups and one piece of foil instead of three cups and unlimited foil.

Appendix 5: Sample Data

Chemical-Grade Potassium Chloride

DATA	Trial 1	Trial 2	Trial 3	Average	Notes
Volume H2O (mL)	100	100	100	100.00	
Mass of H2O (g)	100	100	100	100	Density of water = 1.0 g/ml
Mass of KCl (g)	25	25	25	25	
Initial Temperature (Degrees C)	24	24.5	25	24.5	
Final Temperature (Degrees C)	12	12.5	13	12.5	
Change in Temperature (ΔT) (Degrees C)	-12	-12	-12	-12	
				Known values	
Cp of Water (J/g-Degree C)				4.184	
Molar Mass of 1 mole of Potassium Chloride (g)				74.60	
ΔH of KCl (KJ / mol)				17.22	

Calculations	Trial 1	Trial 2	Trial 3	Average	Notes
Calculation of Q_{exp}					
	-5020.80	-5020.80	-5020.80	-5020.80	
Q_{exp} in kJ	-5.02	-5.02	-5.02	-5.02	Convert to kJ
Calculation of Q_{ideal}					
Q = -ΔHn					
n = m / molar mass	0.34	0.34	0.34	0.34	

Q_{ideal} *in kJ*	-5.77	-5.77	-5.77	-5.77	

Food-Grade Potassium Chloride

DATA	Trial 1	Notes
Volume H2O	100	ml
Mass of H2O	100	Density of water = 1.0 g/ml
Mass of KCl	25	grams
Initial Temperature	24	C
Final Temperature	11	C
Change in Temperature (ΔT)	-13	C
Cp of Water	4.184	J/g-degres C

Calculations	Trial 1	Notes
Calculation of Q_{exp}		
$Q=m * Cp * \Delta T$		
Energy of dissolution	-5439	J
Convert to KJ	-5.44	kJ
Calculation of Q_{ideal}		
$Q = -\Delta Hn$		
ΔH *of KCl*	17.2	kJ/mol